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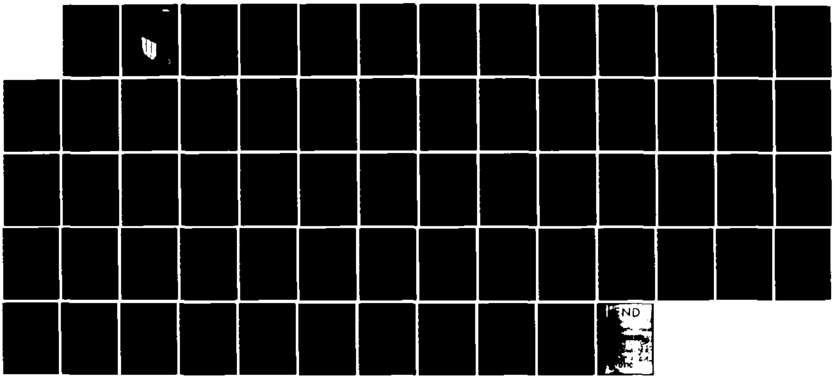

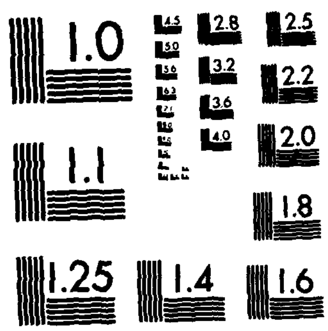

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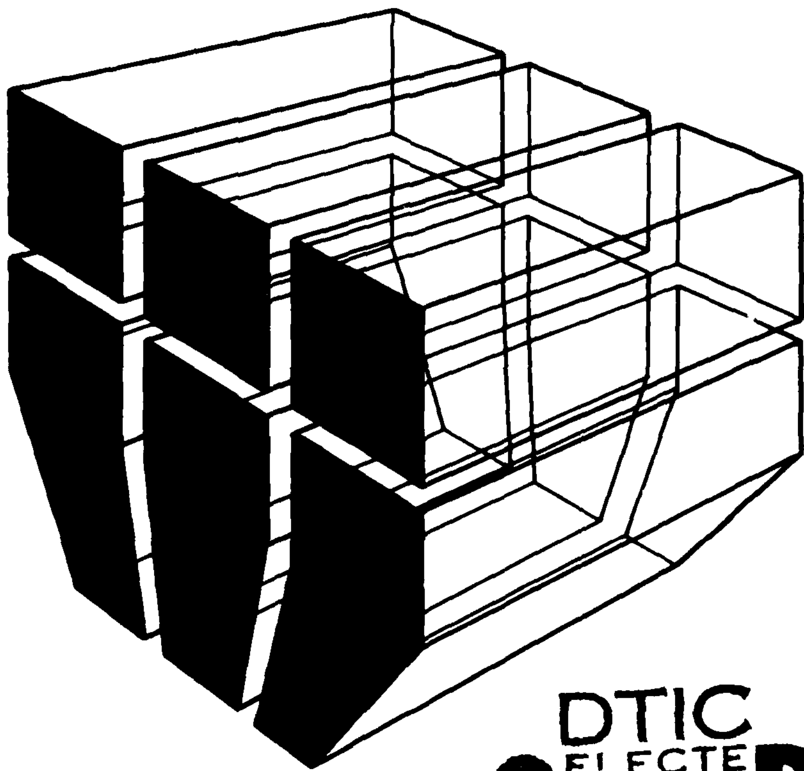
TECHNICAL REPORT P-164
September 1984
Life Cycle Cost Data Base

ECONOMIC ANALYSIS MODELS FOR EVALUATING COSTS OF A LIFE CYCLE COST DATA BASE



by
E. Lile Murphree, Jr.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CERL-TR-P-164	2. GOVT ACCESSION NO. A146807	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ECONOMIC ANALYSIS MODELS FOR EVALUATING COSTS OF A LIFE CYCLE COST DATA BASE		5. TYPE OF REPORT & PERIOD COVERED FINAL 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) E. Lile Murphree, Jr.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Construction Engr Research Laboratory P.O. Box 4005 Champaign, IL 61820-1305		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 6.27.31A 4A762731AT41-A-033
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE September 1984 13. NUMBER OF PAGES 57
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are available from the National Technical Information Service
Springfield, VA 22161

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

life cycle costs
economic analysis
buildings
design

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study has developed economic models representing the various ways of providing designers with maintenance and repair information for evaluating alternative methods for providing data to support military construction design decisions. A plan for evaluating design costs, using these models, was also prepared.

Criteria were developed for selecting modes of supplying the required information. Two models were selected using these criteria: a centralized

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database and ad hoc acquisition by the analyst-designer. A general economic model for data supply was developed for these two modes. The model was shown to be well-defined, and it was determined that the programmer-analyst could easily prepare programs to do the calculations if the required data is available.

FOREWORD

This research was conducted for the Assistant Chief of Engineers under RDT&E Program 6.27.31A, Project 4A762731AT41, Military Facilities Engineering Technology, Task A, "Planning and Design"; Work Unit 033, "Life Cycle Cost Data Base."

The work was performed by Sage Systems Corporation under Contract No. DACA88-81-C-0014 to the U.S. Army Construction Engineering Research Laboratory (USA-CERL). The work is one part of the Life Cycle Cost Data Base work unit. Mr. Robert Neathammer of the USA-CERL Facility Systems Division (FS) was the USA-CERL principal investigator, and Dr. Larry Schindler (DAEN-ECE-G) was the Technical Monitor. Administrative support was provided by Mr. E. A. Lotz, Chief of USA-CERL-FS.

COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

ECONOMIC ANALYSIS MODELS FOR EVALUATING
COSTS OF A LIFE CYCLE COST DATA BASE

1 INTRODUCTION

Background

The Corps of Engineers (CE) will use Life Cycle Cost Analysis (LCCA) as an integral part of the design process supporting the Military Construction, Army (MCA) program. MCA design is done in-house at designated CE Districts and by contract with Architect-Engineers. Design reviews are done in-house at CE Districts.

There are three factors behind the decision to use LCCA:

1. Higher authority has directed that the CE use LCCA; also, in some areas, such as environmentally sensitive projects, the law requires use of LCCA.

2. It is the clear intent of Congress that LCCA be used.

3. The CE believes that LCCA, if it can be implemented cost-effectively, will provide better designs by lowering life cycle costs for facilities in terms of costs for training, procedures, data, etc.

To produce a reliable LCCA, the designer/analyst must have timely access to accurate, reliable data. This is true for every analysis, regardless of how the calculations are performed. However, absolute levels of accuracy and reliability are not required. The data need only be accurate enough to support a design decision; it must be reliable enough to control uncertainty to an acceptable level.

A Technical Manual describing LCCA techniques and applications is being prepared for use in the field.

Several alternative scenarios are available for providing data to the analyst. These range from a fully automated, computer-based, centrally developed and maintained data base, accessible on short notice by any analyst at any location within or outside of the CE; through Division- or District-maintained data bases; to a policy of requiring each analyst to develop, on an ad hoc basis, the data required for each analysis.

The CE must complete three major tasks to develop a plan for supplying data to support the LCCA policy:

1. The viable alternative methods for supplying necessary data must be made clear, along with pertinent user behaviors associated with each which would affect the differential costs of using that alternative.

2. Mathematical models expressing the differential costs for each alternative, Corps-wide, must be developed, along with data requirements and sources for each model.

3. The models must be exercised with live data to produce a range of expected differential costs for the selected alternative data supply schemes.

This report addresses tasks 1 and 2 and discusses the development of a plan to exercise the developed mathematical models.

Objective

The objectives of this study were (1) to develop economic models representing the various ways of providing designers with maintenance and repair (M&R) data for evaluating each alternative and (2) to prepare a plan for evaluating the costs, using the models.

Approach

The major tasks done for this study were:

Task 1. Developing viable alternate modes of providing data to designers by identifying users, techniques, data requirements, data sources, etc.

Task 2. Preparing criteria for evaluating the viable alternate methods.

Task 3. Developing economic decision models of the alternate methods and demonstrating the feasibility of each model.

Task 4. Preparing data requirements for decision models, including cost estimated for data collection.

Task 5. Preparing a plan for making recommendations for the Corps of Engineers for a decision on data-providing methods, including estimates of required staff and resources, cost estimates for the analyses, and a report on the analyses.

On-site interviews were done to insure as much practical input as possible from the Districts which have been using and will continue to use LCC analysis. The interviews centered on past experience in conducting LCC studies; sources of M&R data for those studies; planned procedures for providing M&R data locally, if required; expected future sources of M&R data; and preferences as to form and media for delivery of M&R data from a central data bank, if one should be developed. Interviews were held with the Chief (or his representative) of the Mechanical-Electrical Section, the Architectural Section, and the Estimating Section of the Military Branch (or the organizational equivalents) at the Fort Worth, Savannah, and Sacramento Districts. Detailed reports on each of the sets of interviews are attached as an Appendix. The conclusions formed from the interviews are the basis for the viable alternate modes of data supply.

2 FACTORS IN DATA REQUIREMENTS

Users

The preparers of DD Forms 1391 and design brochures clearly need M&R data, at least at the generic systems level of detail; however, the bulk of life cycle cost analysis is expected to be performed by facility designers, either at Districts or at Architect-Engineer (A-E) firms doing design under contract to the Corps. The remainder of this report deals with providing LCC data to these designers.

Techniques

Every facility subsystem is comprised of components; the components are connected to one another in various ways (physically or operationally), and collectively provide a new, distinct entity--the system itself. For example, the boilers, controls, ducts, valves, and piping are components of an HVAC system. The HVAC system exists only when the components are appropriately connected. Every component has its own M&R life experience; the system as a whole also has its own separate M&R life experience, which involves not only the components, but also the interfaces between components (e.g., the joints between sections of ducting). At a second level of interdependence, the M&R experience of any components may be materially influenced by the nature of the system of which it is a part. For this study, we will concentrate only on the M&R experience at the first level, i.e., that of the individual components and that of the system as a whole.

Both maintenance and repair activities require the performance of specific tasks on a given system component at one or more points over the period of time of interest--often the entire life of the component. The cost elements which contribute to the total costs of both maintenance and repair operations are conceptually identical. The bases for occurrence of the two types of operations, however, are fundamentally different. What is important is to note that for each component (and for the system as a whole), both maintenance and repair activities create a stream of costs occurring at different times, and that there is such a stream of costs for each type of maintenance or repair activity for each component.

Suppose, for example, that a certain light fixture must be cleaned every second year and that the lighting elements are to be replaced annually for the next 20 years, the time horizon of interest. Let the cleaning operation (#1) schedule be represented by the set $T_1 = \{2, 4, 6, 8, ---, 18\}$, and the replacement operation (#2) schedule by $T_2 = \{1, 2, ---, 19\}$. (In this example, the schedules are regular, but this need not be the case, generally.) Let the cost of performing the cleaning operation one time, in current dollars, be X_1. The annual rate of discount is i and the relative inflation factor for year k is e_k. The present value of costs to perform the cleaning operation on the fixture every other year for 20 years is, then,

$$P_1 = X_1 \sum_{k \epsilon T_1} \frac{e_k}{(1+i)^k} \qquad \text{[Eq 1]}$$

For operation 2, the present value is

$$P_2 = X_2 \sum_{k \epsilon T_2} \frac{e_k}{(1+i)^k} \qquad \text{[Eq 2]}$$

where X_2 represents the current cost of performing operation #2 one time, and T_2 represents the schedule for operation #2.

The present value of both maintenance operations for the light fixture is, then,

$$P = P_1 + P_2. \qquad \text{[Eq 3]}$$

In reality, maintenance operations and repair operations are identical in structure, with the important difference that maintenance operations can be deterministically scheduled far in advance, while repair operations, by definition, take place when something breaks or fails. That is, the schedule for repairs on a component must be determined stochastically, based on experienced failures. The concept of <u>mean time to failure</u> (or <u>MTTF</u>) of a specific failure type on a particular component provides a conceptual tool to prepare probable repair schedules for components in the same format as maintenance schedules.

Eq 1 can now be extended to include both maintenance and repair operations of all kinds for all components (and the systems themselves) of all systems comprising a facility.

Generalizing Eq 1, we have

$$P = \sum_{s \epsilon S} \sum_{c \epsilon C_s} \left[\sum_{m \epsilon M_{c,s}} \sum_{k \epsilon T_{m,c,s}} X_{m,c,s} \frac{e_k}{(1+i)^k} + \sum_{r \epsilon R_{c,s}} \sum_{h \epsilon U_{r,c,s}} Y_{r,c,s} \frac{e_h}{(1+i)^h} \right] \qquad \text{[Eq 4]}$$

where:

i, e_j = discount rate and relative inflation factor, respectively, at period j

$Y_{r,c,s}$ = cost of repair procedure r on component c of system s, in current dollars

$X_{m,c,s}$ = cost of maintenance procedure m on component c of system s, in current dollars

$U_{r,c,s}$ = {u|u is a point in time when repair procedure r is <u>anticipated</u> to be required on component c of system s}

$T_{m,c,s}$ = {t|t is a point in time when maintenance procedure m is <u>scheduled</u> to be performed on component c of system s}

$R_{c,s}$ = {r|r is a repair procedure specified for component c of system s}

$M_{c,s}$ = {m|m is a maintenance procedure specified for component c of system s}

C_s = {c|c is a component of system s, <u>or</u> the system as a whole}

S = {s|s is a system of the facility}

P = present value of M&R for the facility.

Examination of the variables in Eq 4 provides a guide to the data requirements to support a comprehensive program of life cycle cost analysis integrated into the MCA design program. For every component of every system of interest in the LCC analysis program (and, separately, for every such system as a whole), a list of the required maintenance procedures and the expected repair procedures is needed. For each listed procedure, a schedule and a current local cost to perform the procedure one time are required. Finally, the following are needed: a discount rate, i; a set of relative inflation factors $E = \{e|e_k$ is the inflation factor chosen for the k^{th} period after construction}, relative to the factor for period 0, where $E_0 = 1.00$. With these sets of data, comprehensive life cycle cost analyses can be performed in the most general situations. Eq 4 is independent of the source of the data sets.

<u>Data Characteristics</u>

This section discusses the several categories of data required for LCC analysis in the design process and the characteristics of these data which have an important impact on the practical implementation of an LCC analysis program.

A Corps-wide program will require a certain degree of uniformity, while allowing for significant geographical differences. The discount rate, i, and the relative inflation factors, e, are both the kind of data which are most likely to be established at the level of the Office of the Chief of Engineers or higher, and not subject to local modification. Accordingly, neither i nor e will be further considered in this report.

Specifications for Corps of Engineers projects do not normally specify equipment by manufacturer and model, but allow the contractor some leeway in specific equipment selection. Therefore, the designer does not know, at design time, exactly what items will be installed. The impact on LCC analysis of this practice is that M&R data must be available on <u>generic systems and components</u>, not on specific models of specific manufacturers. There are both positive and negative aspects of this. The positive is that less data must be maintained, with one generic set perhaps representing several proprietary systems. The negative is that ways must be devised to select data on proprietary systems and components that will represent an "average" generic system of the same kind, to a degree that will support reliable design decisions.

The selection of components and systems is a responsibility of the designer. However, the selection of the "master list" of generic components and systems, from which the designer selects for a specific facility design, is the responsibility of the LCC data base designer. This is because it is as important to decide which components and systems go into the data base as it is to decide what representative data are stored for each.

For each component and system chosen for inclusion in the data base, Eq 4 requires three sets of data for maintenance operations and three for repair operations. That is, for M&R, the following are required: (1) a list of procedures, (2) a schedule of when the procedures are to be (or are expected to be, in the case of repairs) performed, and (3) a current cost to perform (one time) the procedure at the location of the facility. These data form the bulk of any LCC data base; their accuracy directly influences the accuracy of the analyses, and therefore the quality of the design decisions. In light of the importance of these data, it is useful to examine their sources.

Maintenance and Repair Costs

A practical approach to development of M&R data is the use of so-called Engineered Performance Standards (EPS). Rather than relying on historical records of when maintenance was performed and related costs, the EPS approach involves the development of standard procedures to be performed at pre-determined times. The resulting maintenance plans reflect optimum care for components and systems, and provide a stable base for cost projections over the life cycle. The EPS development process is the same for both maintenance and repair procedures, except that maintenance schedules are deterministic and repair schedules are stochastic.

For each component or system, a list of M&R procedures is required first. Then, this information must be developed for each procedure.

1. A schedule for its performance

2. Tools (or equipment) to perform the procedure

3. Labor (required skills, number of workers)

4. Consumable materials and parts

5. Duration of time required to perform the procedure

6. Variable times, e.g., time to get access to the equipment to be serviced

7. Unit costs for tools, labor, and consumables and parts.

This information, complete for each procedure, allows establishment of two things required for use of Eq 4, and which form the foundation of LCC analysis:

1. $Y_{r,c,s}$ and $X_{m,c,s}$, the current cost of performing procedure r or m one time (items 2 through 7)

2. $U_{r,c,s}$ and $T_{m,c,s}$, the <u>expected</u> points in time during the life of component c when procedure r or m will be performed (item 1).

Placing the data in set theoretic notation gives the following sets:

$Q = \{q|q_j$ is the number required of equipment $j\}$

$L = \{l|l_j$ is the number required of craft $j\}$

$N = \{n|n_j$ is the number required of part $j\}$

$K = \{k|k_j$ is the cost allocation in dollars per hour for equipment $j\}$

$V = \{v|v_j$ is the cost allocation in dollars per hour for craft $j\}$

$W = \{w|w_j$ is the cost allocation in dollars each for part $j\}$

t = time in hours required to perform procedure m or r

g = time in hours associated with the procedure at the site of interest, e.g., travel or access time.

While each set defined above is properly subscripted to reference <u>procedure</u>, <u>component</u>, and <u>system</u> (e.g., $Q_{m,c,s}$, $N_{r,c,s}$), the context of the present discussion is a <u>single procedure</u>, allowing us to discard, for the moment, the subscripts.

Total cost of the procedure is the sum of labor cost, equipment cost, and parts cost.

Labor cost = time x number of workers x hourly costs

$$= (t+g) \sum_j l_j \cdot v_j$$

Equipment cost = time x number of pieces of equipment x hourly costs

$$= (t+g) \sum_j q_j \cdot k_j$$

Parts cost = number of parts x cost per part

$$= \sum_j n_j \cdot w_j$$

Summing these costs, we have, for a maintenance procedure,

$$X_{m,c,s} = (t+g) \left[\sum_j l_j \cdot v_j + \sum_j q_j \cdot k_j\right] + \sum_j n_j \cdot w_j \qquad \text{[Eq 5]}$$

The same equation holds for a repair procedure, yielding $Y_{r,c,s}$, with appropriate data sets.

For example, suppose a certain type of heating system component with a life expectancy of 20 years requires a thorough cleaning every 2 years. This cleaning procedure is done by a crew of one plumber, one electrician, and two laborers, and takes 14 hours. Travel and access time totals an additional two hours. Seven gallons of cleaner at $3.00/gal, four filters at $17.00 each, and a dozen disposable cloths at $1.50/dozen, are used in the procedure. A pickup truck, at a cost of $6.00/hour, and small tools, at a cost of $0.50/hour, are also used by the crew. Total hourly cost is $17.37 for a plumber, $18.21 for an electrician, and $9.66 for a laborer.

The equipment complement is, then:

1. Pickup truck

2. Small tools

and the quantity of each is shown by

$Q = \{1, 1\}$, and the hourly costs by

$K = \{\$6.00, \$0.50\}$.

The labor crew is:

1. Plumber

2. Electrician

3. Laborer

and the quantity of each is shown by

$L = \{1, 1, 2\}$, and the hourly costs by

$V = \{\$17.37, \$18.21, \$9.66\}$

The parts set is:

1. Cleaner

2. Filter

3. Disposable cloths

and the quantity of each is shown by

$N = \{7, 4, 1\}$, and the unit costs by

$W = \{\$3.00, \$17.00, \$1.50\}$.

The time t required to perform the procedure is 14 hours; variable time g is 2 hours.

The total cost for performing this maintenance procedure one time, in current dollars, can now be calculated from Eq 5.

$$X_{m,c,s} = (14 + 2) \{[(1 \cdot \$17.37) + (1 \cdot \$18.21) + (2 \cdot \$9.66)]$$
$$+ [(1 \cdot \$6.00) + (1 \cdot 0.50)]\} + [(7 \cdot \$3.00) + (4 \cdot \$17.00)$$
$$+ (1 \cdot \$1.50)]$$
$$= (16) [\$61.40] + \$90.50$$
$$X_{m,c,s} = \$1072.90$$

This schedule calls for this procedure to be done every 2 years throughout the expected lifetime of the component of 20 years. The schedule is, then,

$$T_{m,c,s} = \{2, 4, 6, ---, 18\}$$

Note that the procedure is not performed at the 0th year, since the component is new and presumably needs no maintenance, nor at the 20th year, since the expected life of the component has been reached, and replacement is anticipated (or retirement of the system of which it is a part).

The portion of the present value P of <u>that part of the maintenance program due to the example procedure only</u> can be calculated from Eq 4, if we have values for e_k and i. From Eq 4,

$$P_{m,c,s} = \sum_{k \varepsilon T_{m,c,s}} X_{m,c,s} \frac{e_k}{(1+i)^k} . \qquad [\text{Eq } 6]$$

Let $E = \{e | e_{j+1} = e_j + .04,\ e_o = 1.0\}$

corresponding to inflation factors relative to year 0 to years 2, 4, 6, ---, 16, 18 of the component's life. This set of numbers reflects a 4 percent per year linear increase in costs over the period of interest.

Let the discount rate i = 10%. Then,

$$P_{m,c,s} = \sum_{k \varepsilon \{2,4,---,18\}} \frac{e_k}{(1.10)^k}$$
$$= \$1072.90 \left[\frac{1.08}{(1.10)^2} + \frac{1.16}{(1.10)^4} + \frac{1.24}{(1.10)^6} + \ldots + \frac{1.72}{(1.10)^{18}}\right]$$
$$= \$1072.90 [.8926 + .7923 + .6999 + .6158 + .5398 + .4716 + .4108 + .3569 + .3094]$$
$$= \$1072.90 (5.0890)$$
$$P_{m,c,s} = \$5460$$

Thus, while the procedure costs \$1072.90 to perform one time now (i.e., at year 0), the procedure's cost for the life of the component has a present value $P_{m,c,s}$ of \$5460.

Recapitulation

Each facility is composed of distinct systems; each system is composed of components. The cost of M&R for the facility is the sum of the M&R costs of the systems; the system M&R costs are the sum of the component M&R costs. The M&R costs occur over a number of years and escalate with inflation. Present values of the streams of annual component M&R costs, appropriately discounted, allow the analysis to compare alternative designs in a consistent manner.

From Eq 5, there is a procedure to calculate rigorously the current one-time cost for each maintenace and each repair procedure for each component of each system. In the following, wherever $X_{m,c,s}$ appears, $Y_{r,c,s}$ can be substituted, if the context is repair rather than maintenance.

$$X_{m,c,s} = (t + g) \left[\sum_j l_j \cdot v_j + \sum_j q_j \cdot k_j\right] + \sum_j n_j \cdot w_j \qquad \text{[Eq 7]}$$

where the variables are as defined in the previous section.

Eq 4 gives a procedure to calculate rigorously the present value of M&R costs for a <u>single</u> M or R procedure; for <u>all</u> the M&R procedures for a <u>single</u> component; for <u>all</u> the M&R procedures for <u>all</u> the components of a selected system; or for <u>all</u> the systems in a facility.

$$P = \sum_{s\epsilon S} \sum_{c\epsilon C_s} \left[\sum_{m\epsilon M_{c,s}} \sum_{k\epsilon T_{m,c,s}} X_{m,c,s} \frac{e_k}{(1+i)^k} + \sum_{r\epsilon R_{c,s}} \sum_{h\epsilon U_{r,c,s}} Y_{r,c,s} \frac{e_h}{(1+i)^h}\right] \qquad \text{[Eq 8]}$$

where the variables are as defined in the previous section.

The calculations implied by Eq 7 can be simplified by the assignment of a single lump sum figure to the cost of a procedure:

$$X_{m,c,s} = A_{m,c,s} \qquad \text{[Eq 9]}$$

$$Y_{r,c,s} = A_{r,c,s} \qquad \text{[Eq 10]}$$

The present value of the cost of a single procedure for the life of a component can be simplified likewise:

$$\sum_{k\epsilon T_{m,c,s}} A_{m,c,s} \frac{e_k}{(1+i)^k} = B_{m,c,s} \qquad \text{[Eq 11]}$$

$$\sum_{h\epsilon U_{r,c,s}} A_{r,c,s} \frac{e_h}{(1+i)^h} = B_{r,c,s} \qquad \text{[Eq 12]}$$

The present value of all M&R costs for the life of a component can also be simplified:

$$\sum_{m \epsilon M_{c,s}} B_{m,c,s} = C_{M,c,s} \qquad \text{[Eq 13]}$$

$$\sum_{r \epsilon R_{c,s}} B_{r,c,s} = C_{R,c,s} \qquad \text{[Eq 14]}$$

And, finally, the present value of the M&R costs for all the components (plus the system itself) of a system can be represented as a single figure:

$$\sum_{c \epsilon C_s} (C_{M,c,s} + C_{R,c,s}) = D_s \qquad \text{[Eq 15]}$$

The present value of M&R for the facility then becomes:

$$P = \sum_{s \epsilon S} D_s \qquad \text{[Eq 16]}$$

Alternately, we have

$$P = \sum_{s \epsilon S} \sum_{c \epsilon C_s} (C_{M,c,s} + C_{R,c,s}) \qquad \text{[Eq 17]}$$

We now have a spectrum of "packages" for presenting M&R data to the analyst-designer, ranging from detailed cost analysis at the single procedure level, through lump sum estimates of life cycle M&R costs at the component level, to total M&R costs at the systems and facility levels. The computational framework for rigorous analysis is left intact, while the facilities for analyses based on less detailed design or cost information are now in place.

Chapter 3 considers the implications to the supplier of data of the design process followed in CE design; the analyst-designer's M&R data needs at various stages in the design process; the opportunities for alternative data packaging; and the practical realities of getting reliable data.

3 DATA SUPPLY

The Design Process

The CE design process for the MCA program is structured in three distinct phases: Concept, Advance Final, and Final Design. Cost estimates are prepared at each phase, and LCC analyses are necessary to support design decisions during each phase. Design detail increases from Concept to Final Design phase. In the Concept Design phase, decisions must be made on the basis of life cycle costs (including M&R costs) aggregated at the facility system level (structural frame, cladding, mechanical, roof and roofing, interior wall finish, flooring, fenestration, etc.).

For this level of design, knowledge by the designer of the composition of the systems is not detailed enough to support a more detailed LCC analysis than is represented by Eq 16, i.e.,

$$P = \sum_{s \in S} D_s \qquad \text{[Eq 18]}$$

Where D_s represents the present value of the M&R costs for a selected system s from a set of functionally equivalent systems. For example, D_s might represent the present value of the M&R costs for a gas-fired furnace chosen from a set of alternatives consisting of

1. Gas-fired

2. Oil-fired

3. Coal-fired

4. Electric

What is implied here is that for every $s \in S$, there is a set $\mathscr{S}$ of alternate systems $\mathscr{s}$ from which s is chosen by the designer to be an element of a particular facility design.

$$\mathscr{S} = \{\mathscr{s} \mid \mathscr{s}_i\text{'s are functionally equivalent systems}\}$$

In the example above,

$$\mathscr{S} = \{\text{Gas-Fired Furnace, Oil-Fired Furnace, Coal-Fired Furnace, Electric Furnace}\}$$

The analyst-designer chooses $\mathscr{s} \in \mathscr{S}$ as a part s of his* facility design S; $\mathscr{s} \equiv s$, so that $s \in S$. To evaluate the impact of the design decision on the M&R costs for the facility, the M&R costs for s must be transformed into D_s for the particular facility under design, using facility design data available at Concept Design time and such M&R data as is available in appropriate form and

*The male pronoun is used to refer to both genders.

quality. This generally means that, from DD Form 1391 and the Project Development Brochure, the pertinent facility parameters and design constraints known are those shown in Table 1.

For every $\mathcal{s}\epsilon\mathcal{S}$, then, M&R data must be available in a form that will support the development of $D_{\mathcal{s}}$ for every $\mathcal{s}$ the analyst-designer chooses to consider for $s\epsilon S$. A compromise must be made. On one hand, from Eqs 9 through 15, $D_{\mathcal{s}}$ is a function of task, component, and economic data unknown at Concept Design time. On the other hand, from Table 1, facility data known at the time is unsupportive of the constructive definition of $D_{\mathcal{s}}$ as shown by Eq 8 and subsequent equations.

Data To Support Concept Design

M&R data for use at Concept Design time must, then, be in a form that allows particularization to acceptable accuracy by the analyst-designer to the facility in design by use of the known facility parameters, such as those in Table 1. To support the set of alternate systems $\mathcal{S}$, there must be a related set of unit cost data Δ, such that

$$\Delta = \{\delta | \delta_i \text{ is unit M\&R cost data for system } \mathcal{s}_i \mathcal{S}\}$$

For example, from the following,

$$\mathcal{S} = \{\text{Gas-Fired Furnace, Oil-Fired Furnace, Coal-Fired Furnace, Electric Furnace}\}$$

and $\Delta = \{\delta_1 \text{ \$/sq ft}, \delta_2 \text{ \$/sq ft}, \delta_3 \text{ \$/sq ft}, \delta_4 \text{ \$/sq ft}\}$

and allow an analyst to calculate, to an acceptable degree of accuracy for concept design, the present value of M&R costs for each of the four alternate furnace types by simply multiplying the unit cost δ_i in \$/sq ft times the floor area of the facility.

$$D_{\mathcal{s}_i} = \delta_i \times \text{Area}$$

$D_{\mathcal{s}_i}$, then, is the present value of the ith competing design. When the designer chooses from the competing designs, then the present value of the chosen design becomes D_s; s represents the system actually placed in the overall facility design. The development in Eqs 7 through 17 shows that D_s is a function of several variables:

$$D_s = f(t, g, q, l, n, k, v, w, E, i, T, U, M, R, C), \qquad \text{[Eq 19]}$$

where the variables are as defined in Chapter 2.

Regrouping the variables gives the data sets shown in Table 2.

For a given type of system, the components, procedures, and schedules remain constant over many years. Crew size and performance times are relatively stable, barring introduction of disruptive technology (e.g., self-propelled floor scrubbers as a replacement for labor-intensive hand mopping). Unit cost allocations are not stable and are subject to change at

Table 1

Facility Parameters Known at Concept Design Time

Geographic location (installation, state, country)
Facility type (warehouse, BOQ, hospital)
Type of construction (permanent, temporary)
Type of work (new, remodel)
Type of design (standard, special)
Physical characteristics of primary facility
- Line drawings
- Number of buildings
- Number of stories
- Length
- Width
- Site data

Outline specifications
Design capacity (sq ft, cu ft)
Gross area (sq ft)
Cooling (capacity, cost)
Cost estimate
Related projects (e.g., supporting facilities)

Table 2

Sets of Data To Support Rigorous LCC Analysis

1.	$\{t, g\}$	:	hours to perform procedures
2.	$\{q, l, n\}$	:	numbers of equipment and parts
3.	$\{k, v, w\}$	:	unit cost allocations
4.	E	:	inflation factors
5.	i	:	discount rate
6.	$\{T, U\}$	:	schedules for procedures
7.	$\{M, R\}$	:	sets of procedures
8.	C_s	:	set of components for system s

least annually. The inflation factors E are present in the functions to adjust unit costs in future years. Both E and the discount rate i are fixed over long time periods to ensure consistency in LCC analyses geographically and temporally.

As long as unit cost allocations do not change radically relative to one another, then once D_s for any system s has been calculated, it can be advanced year by year without loss of reliability by multiplying by an appropriate inflation factor. Since all costs are tied internally to analysis year 0 costs through the set E, and i is constant, no other corrections are required to retain accuracy. If, for example, D_s = \$19,763 for system s installed in year 1980, and 12.5 percent inflation was experienced from mid-1980 to mid-1981, then D_s = 1.125 x \$19,763 = \$22,233 if installation is expected in 1981. Both installation in 1980 and in 1981 anticipate the same system life, say 25 years, from the installation date.

While this simple correction is easy to use, it does not completely address the problem of supplying data to the analyst-designer at Concept Design time. Eq 4 allows the analyst-designer to perform a rigorous LCC analysis on a particular, though generic, system. Pre-packaging elements of the expression to reduce the labor of computing a system M&R present value is analogous to pre-packaging the system itself: there is no guarantee that either will be appropriate for a specific facility. In order for pre-packaged system-level data to be usable at Concept Design time, it must be expressed in terms of the facility variables known at that time; i.e., one or more of the parameters in Table 1. The knowledge that a built-up roofing system for a facility covering 200,000 sq ft has a present value for M&R of \$17,000 is not immediately useful to a designer of a 300,000-sq-ft facility of the same kind; however, the information that the present value is \$0.085/sq ft for M&R for buildings of this type (100,000 to 400,000 sq ft roof area) allows the designer to quickly extrapolate to a present value of 0.085 x 300,000 = \$25,500 for his design.

The previous example presupposes a linear relationship between M&R costs and roof area, which may or may not be the case for roofs or for building systems in general. What is important in the present context are the assumptions that (1) a relationship can be found empirically between M&R costs and the building parameters known at Concept Design time, (2) these relationships can be determined economically, (3) key data can be expressed economically, concisely, and accurately to the analyst-designer, (4) the time and effort required to customize the data to a particular concept design is consistent with the accuracy of the input data, and (5) the resulting M&R estimates are acceptably accurate to support design decisions at Concept Design time.

Each of these assumptions must be tested for each system included in a Concept Design-level M&R database. Assuming a constructive approach using the EPS concept, the data supplier must, in addition to providing the basic data in Eq 19, perform the following tasks in order to package data appropriately for use at Concept Design time.

Task 1

Exercise the model, with a spectrum of data values represented by Eqs 7 and 8, enough times to generate a valid statistical universe for each system; from this, the first two assumptions above can be tested and substantiated so that a relationship can be found, and found economically, between M&R costs and the building parameters known at Concept Design time.

Task 2

Determine how to present the key data discovered in Task 1 in such a way as to support the last three assumptions above to minimize user time while retaining required accuracy.

Task 3

Generate and display the aggregated Concept Design-level data to the analyst-designer who is to use it, ensuring timely updates as required by significant changes in the parameters of Eq 19. Practically speaking, this will likely be confined to updates to relative inflation factors.

The tasks which the data supplier must perform to support the analyst-designer in the Advance Final and Final Design phases are considered in the next section. These tasks must also be performed prior to the three supporting tasks unique to Concept Design just discussed.

Data To Support Advance Final and Final Design

While specifics may change as a design moves from the Advance Final to the Final Design phase, the designer has no increment in the level of detail of knowledge of components and systems. Consequently, data requirements of both phases can be treated as a single entity, without loss of rigor. By the time the Advance Final phase has ended, every system has been configured and the set of components for each must be known. The implications of this are that the designer must synthesize a set of alternate generic system designs $\mathscr{S}$, perform LCC analysis $D_{\mathscr{s}}$ on each $\mathscr{s} \in \mathscr{S}$, and select a final $\mathscr{s} \equiv s$, which becomes a part of the design, $s \in S$; further implications are that the process requires system assembly from appropriate components, each of which has associated with it an M&R cost value. In the terminology of Eqs 13 and 14, the present value of the M&R costs for a single component c of system s is

$$P_{c,s} = \sum_{m \in M_{c,s}} B_{m,c,s} + \sum_{r \in R_{c,s}} B_{r,c,s} \qquad \text{[Eq 20]}$$

In other words, it represents the sum of the present values of the maintenance tasks and the repair tasks.

While it is probable that in most design situations in this phase that data presented at the level of detail of Eq 20 would be adequate, the data supplier must nevertheless construct the design data by using Eqs 7 and 8, and package it by using Eqs 9 through 14; the analyst-designer must also have the ability (and supporting data) to develop component-level data from its elements in order to perform analyses for project-unique situations. To support analyses up to system level, this obligates the data supplier to provide data for every variable given in Table 2; to aggregate elementary data for components with Eqs 9 through 14 and Eq 20, where feasible; and to provide the lump sum cost figure A, B, C, D for those cases where constructive values cannot be produced. Expanded, these sets of data which must be supplied to the analyst-designer to support LCC analysis at Advance Final - Final Design time are as shown in Table 3. Variables are as defined previously.

The M&R cost for a single component lies at the heart of LCC analysis at this level of detail. It is useful at this point to examine the different ways that the analyses may be carried out, depending on availability of data. Eqs 7 and 8 present the rigorous approach and the framework for all other approaches. Against the backdrop of Eqs 9 through 14, the following calculation steps in a typical LCC analysis for a single component can be itemized:

T_1: One-time cost of a procedure (M or R)

T_2: Present value of a procedure for the life expectancy of the component

T_3: Present value of all procedures for the life expectancy of the component

We consider the alternative ways of performing each step facing the analyst-designer:

T_1: <u>One-time cost of a procedure</u>.

Table 3

Sets of Data To Support Advance Final - Final Design

1.	$\{t, g\}$	:	hours to perform procedures
2.	$\{q, l, n\}$	:	numbers of equipment, workers, and parts
3.	$\{k, v, w\}$	:	unit cost allocations
4.	E	:	inflation factors
5.	i	:	discount rate
6.	$\{T, U\}$	:	schedules for procedures
7.	$\{M, R\}$	:	sets of procedures
8.	C_s	:	set of components for system s
9.	$\{A_{m,c,s}, A_{r,c,s}\}$	:	lump sum cost for a procedure
10.	$\{B_{m,c,s}, B_{r,c,s}\}$	:	present value of cost for a procedure
11.	$\{C_{M,c,s}, C_{R,c,s}\}$	:	total present value for all procedures
12.	D_s	:	present value, lump sum for system

This step can be done rigorously by Eq 7,

$$IA_m : X_{m,c,s} = (t+g)[\sum_j l_j \cdot v_j + \sum_j q_j \cdot k_j] + \sum_j n_j \cdot w_j,$$

or by assigning a single lump sum value to $X_{m,c,s}$,

$$IB_m : X_{m,c,s} = A_{m,c,s},$$

and correspondingly for $Y_{r,c,s}$, IA_r, and IB_r.

T_2: Present value of a procedure.

The options are to calculate from Eq 8,

$$IIA_m : \sum_{m \in M_{c,s}} \sum_{k \in T_{m,c,s}} X_{m,c,s} \frac{e_k}{(1+i)^k},$$

or to assign a single lump sum value,

$$IIB_M : P_M = C_{M,c,s},$$

and correspondingly for P_r, IIA_r, and IIB_r. Note that Option IIA_m is independent of the source of $X_{m,c,s}$, and that Option IIB_m requires no prior determination of a value for $X_{m,c,s}$, or $Y_{r,c,s}$.

T_3: Present value of all procedures.

The options are to calculate from Eq 8,

$$IIIA_M : P_M = \sum_{m \in M_{c,s}} \sum_{k \in T_{m,c,s}} X_{m,c,s} \frac{e_k}{(1+i)^k},$$

or to assign a single lump sum value,

$$IIIB_M : P_M = C_{M,c,s},$$

and correspondingly for P_R, $IIIA_R$, and $IIIB_R$. Note that Option $IIIA_M$ is independent of the source of $X_{m,c,s}$, and that Option $IIIB_M$ requires no prior determination of a value for $X_{m,c,s}$ or $Y_{r,c,s}$.

Figure 1 graphically presents the data options facing the analyst and the progression of the analysis.

In Figure 1, data flows upward to the completed Present Value P_c for the component. In each box, OR represents a choice of data form; e.g., IA_m OR IB_m represents the choice in a particular analysis to use the constructive value for $X_{m,c,s}$ or the lump sum value $A_{m,c,s}$. Examples of the choices of data leading to a P_c are reflected in the following versions of Eq 8:

$$(1) \quad P_c = \sum_{m \in M_{c,s}} \sum_{k \in T_{m,c,s}} X_{m,c,s} \frac{e_k}{(1+i)^k} + C_{R,c,s}$$

$$(2) \quad P_c = \sum_{m \in M_{c,s}} [\sum_{\substack{k \in T_{m',c,s} \\ m' \cup m'' = m}} X_{m',c,s} \frac{e_k}{(1+i)^k} + B_{m'',c,s}] + \sum_{r \in R_{c,s}} B_{r,c,s}$$

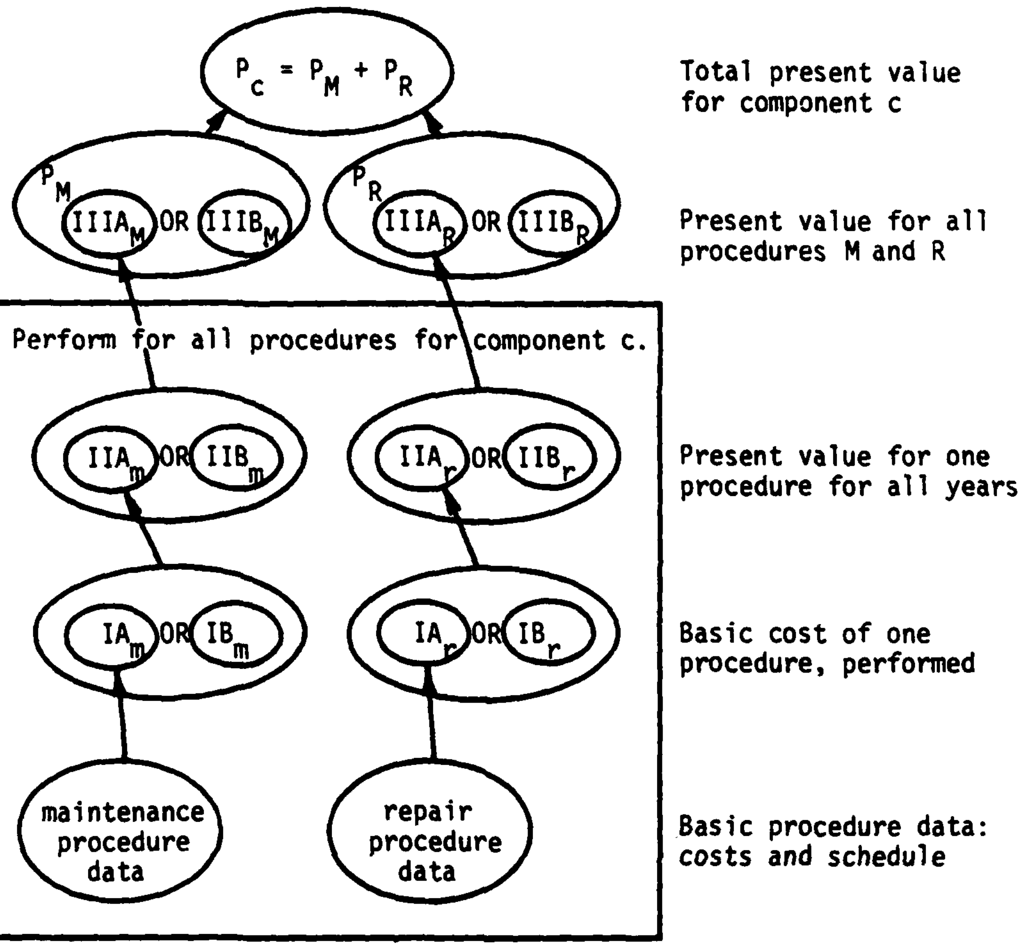

Figure 1. Flow diagram representing data options and analysis progression.

where rigorous calculations are made for some maintenance costs (m') and a lump sum is assumed for others (m"), and a set of lump sums is assumed for the repair costs.

Example (1) here requires, at a minimum, that data be available to support IA_m and $IIIB_r$. Example (2) requires that data support some IA_m and some IB_m, and also IIB_r. In general, the distribution and magnitude of data support depend on the patterns of assembly of P_c, which in turn depend on the preferences of the analyst-designer, the number of components examined, the systems considered, and the types and numbers of facilities under design.

If the function $f_j(x)$ represents the cost of supplying data to task x by means j, the cost of supplying data for the analysis can be calculated for a single component, and by extension, for the entire MCA program. For example, if $F = \{f_1, f_2\}$, then f_1 represents the cost function associated with supplying data through, say, a central computer database, and f_2 represents the cost function for supplying data through, say, the efforts on an ad hoc basis of the individual analyst-designer.

With this notation, the cost for supplying data by means j to support the analysis represented by Example (1) above is

(1) $f_j\ (P_c) = m_1\ f_j\ (IA_m) + f_j\ (IIIB_r)$

where m_1 represents the number of procedures $m \varepsilon M$.

That for the analysis pattern of Example (2) is

(2) $f_j\ (P_c) = m_1\ f_j\ (IA_m) + m_2\ f_j\ (IB_m) + r_1\ f_j\ (IIB_r)$

where m_1, m_2, and r_1 represent, respectively, the number of procedures $m' \varepsilon M$, $m'' \varepsilon M$, and $r \varepsilon R$.

Note that the data cost for pattern (1) may differ from that of pattern (2); also, a different means $k \neq j$ of supplying this could result in a different cost for the same pattern; i.e., $f_j\ (P_c) \neq f_k\ (P_c)$, even for the same pattern, if $k \neq j$.

The expression of cost of supplying data for analyzing a single component can now be generalized:

$$\begin{aligned} f_j\ (P_c) = {} & m_1 \cdot f_j\ (IA_m) + m_2 \cdot f_j\ (IB_m) + m_3 \cdot f_j\ (IIB_m) + \\ & m_4 \cdot f_j\ (IIIB_m) + \\ & r_1 \cdot f_j\ (IA_r) + r_2\ f_j\ (IB_r) + r_3 \cdot f_j\ (IIB_r) + \\ & r_4 \cdot f_j\ (IIIB_r) \end{aligned} \qquad \text{[Eq 21]}$$

where the coefficients m_i and r_i represent the numbers of times the data is supplied for the calculation.

The cost for data by means j for all the components $c \varepsilon C_s$ of system s is represented by

$$f_j\ (P_s) = \sum_{c \varepsilon C_s} f_j\ (P_c). \qquad \text{[Eq 22]}$$

The cost for data by means j for all the systems $s \varepsilon S$ of a facility α is represented by

$$f_j\ (P_\alpha) = \sum_{s \varepsilon S} f_j\ (P_s) \qquad \text{[Eq 23]}$$

Eqs 21 through 23 do not account for the extra work in developing data for study of alternate systems to guide design decisions, nor for study of alternate components for each of the alternate systems. That is, the analyst-designer actually considers $\cancel{s} \varepsilon \cancel{S}$ before selecting $s \varepsilon S$, the actual system s in the final design S. This additional work is accounted for by the following modifications to Eqs 22 and 23:

$$f_j (P_s) = \sum_{c \epsilon C_s} \gamma_c f_j (P_c) \qquad [Eq\ 24]$$

where γ_c represents the number of times analyses are done for alternatives to component c;

$$f_j (P_\alpha) = \sum_{s \epsilon S} \beta_s f_j (P_s) \qquad [Eq\ 25]$$

where β_s represents the number of times analyses are done for alternatives to system s.

Extending, for the subset of the MCA program for which LCC analysis is to be done for a single year y, we have, for means j,

$$f_j (MCA_y) = \sum_{\alpha \epsilon MCA_y} f_j (P_\alpha) \qquad [Eq\ 26]$$

and from Eq 25,

$$f_j (MCA_y) = \sum_{\alpha \epsilon MCA_y} \sum_{s \epsilon S} \beta_s f_j (P_s) \qquad [Eq\ 27]$$

and from Eq 24,

$$f_j (MCA_y) = \sum_{\alpha \epsilon MCA_y} \sum_{s \epsilon S} \beta_s \sum_{c \epsilon C_s} \gamma_c f_j (P_c). \qquad [Eq\ 28]$$

where MCA_y represents the set of projects in the MCA program for year y.

The present value of the total costs for means j over a horizon of n years, is, from Eq 26,

$$PV_{MCA} = \sum_{y=1}^{n} \sum_{\alpha \epsilon MCA_y} f_j (P_\alpha) \frac{e_y}{(1+i)^y} \qquad [Eq\ 29]$$

where e_y represents a relative inflation factor for year y, and i is the discount rate.

In summary, expressions have been developed that, knowing the costs to supply eight kinds of data for analysis of a single component, and the numbers of components, systems, and facilities to be analyzed in future MCA programs, the present value of the costs for a single means of providing the data can be determined.

Attention can now be given to the practical matters of viable modes of providing data and tailoring the general expressions for each viable mode.

Modes of Supply

A spectrum of modes of supply of data for the analyses is possible. At one end lies the centralized CE-wide computer database, providing up-to-date data on any level immediately on demand, through remote terminals at the analyst-designer's work area that are connected to the central computer. At the opposite end, the individual analyst-designer is required to locate his own data for every analysis performed. At an intermediate level lies a centrally assembled database, available to the analyst-designer through an LCC Data Handbook, which would be updated periodically. At another intermediate level lies a database prepared and maintained at the Division (or District) level, with the data distributed through LCC Data Handbooks.

Criteria for Evaluating Modes of Supply

Not all conceivable scenarios, however plausible, have high enough probability to warrant the expense of a full economic analysis. A serious contender for implementation will exhibit the following features:

1. Consistency with present modes of operation for data acquisition, distribution, and use within the CE

2. Capability for supply of data in quantity and quality required for reliable, timely LCC analyses

3. Demonstrated support by analyst-designers and supervisors now performing LCC analyses in the CE

4. An a priori high probability of being economically justifiable in terms of contribution to the overall cost of the LCC analysis program regarding the benefits to the MCA program of performing LCC analysis at all.

Summary of Viable Modes of Supply

In view of the criteria set up for viable alternative modes of supply, two are suitable for serious examination. Both were mentioned repeatedly during interviews at District design units (see Appendix), and both meet all the stated requirements.

1. Mode 1. Data to be acquired at the OCE level, processed as required, and distributed by means of LCC Data Handbooks, with geographical and inflation modification factors supplied by the same source.

2. Mode 2. Data to be acquired at the District level, on an ad hoc basis, by the individual analyst-designers; limited or no distribution outside local design groups; geographical and inflation factors implicit in the acquired data; all processing of data, including aggregation for system-level analyses at Concept Design time, locally generated; all processing of data for analyses done at the District level by the analyst-designer; no buildup of data bank.

4 ECONOMIC ANALYSIS MODELS

Model for Centralized Data Management (Mode 1)

Eqs 21 through 29 must be particularized to consider explicitly the costs associated with centralized data management. From Eq 28, for the year y, the cost of data for the MCA program, letting the cost function for Mode 1 be f_1 is:

$$f_1\ (MCA_y) = \sum_{\alpha \varepsilon MCA_y} \sum_{s \varepsilon S} \beta_s \sum_{c \varepsilon C_s} \gamma_c\ f_1\ (P_c) \qquad \text{[Eq 30]}$$

With centralized data management, all effort to acquire data and format and distribute it is concentrated at the OCE level. The data acquisition effort on the part of the analyst-designer is negligible. Component data will be prepared one time only for each component $c \varepsilon C_{\cancel{s}}$, for every $\cancel{s \varepsilon S}$, that is, for the master component and system sets from which analyst-designers choose $c \varepsilon C_s$, $s \varepsilon S$, the final designs.

Eq 21 becomes

$$\begin{aligned} f_1\ (P_c) = {} & m_1 \cdot f_1\ (IA_m) + m_2 \cdot f_1\ (IB_m) + m_3 \cdot f_1\ (IIB_m) + m_4 \cdot f_1\ (IIIB_m) + \\ & r_1 \cdot f_1\ (IA_r) + r_2 \cdot f_1\ (IB_r) + r_3 \cdot f_1\ (IIB_r) + \\ & r_4 \cdot f_1\ (IIIB_r) \end{aligned} \qquad \text{[Eq 31]}$$

where the coefficients represent the number of times the data is acquired for calculating the cost for the single component c.

With this data system, specific data is acquired only one time. Consequently, factors γ_c and β_s are unity, leading to

$$f_1\ (MCA_y) = \sum_{\alpha \varepsilon MCA_y} \sum_{s \varepsilon S} \sum_{c \varepsilon C_s} f_1\ (P_c) \qquad \text{[Eq 32]}$$

A complete system will not include data for only elements that appear in a single year y MCA program, but will encompass the MCA program in general. Hence, Eq 32 becomes

$$f_1\ (MCA) = \sum_{\alpha \varepsilon MCA} \sum_{s \varepsilon S} \sum_{c \varepsilon C_s} f_1\ (P_c). \qquad \text{[Eq 33]}$$

Eq 33 provides a total cost for acquiring basic M&R data at the component level to support LCC analysis for Advance Final - Final design. It does not provide for the costs of

1. Processing the data for use at Concept Design

2. Managing, formatting, updating, and distributing the data to users

3. Acquiring the hardware and software required

4. Managing and staffing the entire operation.

Cost increment (1) is a function of that covered already in Eq 33, since it builds directly on that data. It is reasonable, then, to account for this increment by a factor $\xi > 1$.

Cost increments (2) and (4) are also, logically, functions of database magnitude and, therefore, of cost. These increments can be included by the inclusion of a second factor $\psi > 1$.

Cost increment (3), acquiring the hardware and software, is best handled as an added cost increment, as Z, in dollars. Thus:

$$f_1\ (MCA) = Z + \xi \cdot \psi \sum_{\alpha\varepsilon MCA} \sum_{s\varepsilon S} \sum_{c\varepsilon C_s} f_1\ (P_c) \qquad \text{[Eq 34]}$$

where Z = one-time cost for hardware and software

ξ = factor to provide for additional processing of component data for use at Concept Design time

ψ = factor representing the present value of the cost of operations for n years. Other variables are as previously defined.

Eq 34 gives a present value of the acquisition costs for hardware, software, and data, plus the costs to assemble data for use at Concept Design time, plus the operating costs for n years.

Mode for District-Level, Ad Hoc Data Acquisition (Mode 2)

From Eq 21, letting f_2 represent the cost function for this totally decentralized mode,

$$\begin{aligned} f_2\ (P_c) = {} & m_1 \cdot f_2\ (IA_m) + m_2 \cdot f_2\ (IB_m) + m_3 \cdot f_2\ (IIB_m) + \\ & m_4 \cdot f_2\ (IIIB_m) + \\ & r_1 \cdot f_2\ (IA_r) + r_2 \cdot f_2\ (IB_r) + r_3 \cdot f_2\ (IIB_r) + \\ & r_4 \cdot f_2\ (IIIB_r), \end{aligned} \qquad \text{[Eq 35]}$$

where the coefficients represent the number of times the analyst-designer acquires the data for the calculations of cost for the single component c.

From Eq 28,

$$f_2\ (\tilde{M}CA_y) = \sum_{\alpha\varepsilon MCA_y} \sum_{s\varepsilon S} \beta_s \sum_{c\varepsilon C_s} \gamma_2\ f_2\ (P_c) \qquad \text{[Eq 36]}$$

where the variables are as defined earlier.

Eq 36 gives a cost for data acquisition for one year for analyses at Advance Final - Final design time. To increment this cost to cover additional data processing for analyses at Concept Design time, factor ξ is again applied.

$$f_2\ (MCA_y) = \xi \sum_{\alpha \epsilon MCA_y} \sum_{s \epsilon S} \beta_s \sum_{c \epsilon C_s} \gamma_c \cdot f_2\ (P_c) \qquad \text{[Eq 37]}$$

Eq 37 gives a total cost for data for one year.

To compare the costs for Mode 1 with those of Mode 2, the present value for Eq 37 must be calculated over n years.

$$f_2\ (MCA) = \xi \sum_{y=1}^{n} \sum_{\alpha \epsilon MCA_y} \sum_{s \epsilon S} \beta_s \sum_{c \epsilon C_s} \gamma_c\ f_2\ (P_c) \frac{e_y}{(1+i)^y} \qquad \text{[Eq 38]}$$

where the variables are as defined earlier.

Equivalent Annual Costs

An often-used alternative to present value as a common measure of costs of competing alternatives is the equivalent annual cost. This format allows comparison, in current dollars, of the annual costs of competing alternatives, taking into consideration the discount rate and the need to amortize capital costs (here Z, the investment in hardware, software, and data for Mode 1) over a period of years. To convert the present values calculated by Eq 34 or Eq 38 to equivalent annual cost (EAC) in current dollars over n years for Mode k:

$$EAC_k\ (MCA) = f_k\ (MCA) \frac{i(1+i)^n}{(1+i)^n-1} \qquad \text{[Eq 39]}$$

where i = discount rate

n = number of years to amortize

f_k (MCA) is found by Eq 34 or 38, as appropriate.

For Mode 1, Eq 34 is used, and from Eq 39, for its equivalent annual cost:

$$EAC_1\ (MCA) = [Z + \xi \cdot \psi \sum_{\alpha \epsilon MCA} \sum_{s \epsilon S} \sum_{c \epsilon C_s} f_1\ (P_c)][\frac{i(1+i)^n}{(1+i)^n-1}] \qquad \text{[Eq 40]}$$

Similarly, for Mode 2:

$$EAC_2\ (MCA) = [\xi \sum_{y=1}^{n} \sum_{\alpha \epsilon MCA} \sum_{s \epsilon S} \beta_s \sum_{c \epsilon C_s} \alpha_c\ f_2\ (P_c) \frac{e_y}{(1+i)^y}][\frac{i(1+i)^n}{(1+i)^n-1}] \qquad \text{[Eq 41]}$$

Use of Models

The application of the economic models to estimate the costs of data provision by each of the two modes considered here is straightforward. There are two steps:

1. Identify the data elements from Eqs 35 through 39 and acquire these data values.

2. Carry out the calculations specified in Eqs 35 through 39.

That Eqs 35 through 39 are well-defined is prima facie evidence that the exercise of the models is technically feasible. Examples of the application of both models, using assumed values for the variables, are presented in Chapter 5.

5 APPLICATION OF THE ECONOMIC ANALYSIS MODELS

Examples

Mode 1, Centralized Data Management, Present Value

In Eq 34 the general expression for the present value of Mode 1 has been developed:

$$f_1\ (MCA) = Z + \xi \cdot \psi \sum_{\alpha \epsilon MCA} \sum_{s \epsilon S} \sum_{c \epsilon C_s} f_1\ (P_c)$$

where Z = capital investment, in current dollars, for computer hardware and the specialized programs for centralized data management

ξ = factor, $\xi > 1$, to provide for the additional processing of component data for use at Concept Design time, as a percentage of the cost of acquiring the component data

ψ = factor to provide for the present value of the cost of operating the centralized data management system for n years, as a percentage of the cost of acquiring the component data

$\alpha \epsilon MCA$ represents the facilities α in the union of the MCA programs for the next n years for which LCC analyses will be performed

$s \epsilon S$ represents the system $s \epsilon S$ in the facilities α which will be subjected to LCC analysis

$c \epsilon C_s$ represents the components $c \epsilon C_s$ of the systems $s \epsilon S$ which appear in the facilities α of the MCA program over the next n years

$f_1\ (P_c)$ represents the cost, as shown in Eq 31, of acquiring data for the centralized data management system for one component, $c \epsilon C_s$, of system s.

Assume an interest in estimating the present value of the costs that will be incurred in a limited program that provides data on a few common components (e.g., heating systems, roofing systems, and flooring systems). The entire capital investment in the data is expressed by Eq 42,

$$KD = \sum_{\alpha \epsilon MCA} \sum_{s \epsilon S} \sum_{c \epsilon C_s} f_1\ (P_c) \qquad [Eq\ 42]$$

Eq 34 becomes, then,

$$f_1\ (MCA) = Z + \xi \cdot \psi \cdot KD \qquad [Eq\ 43]$$

Let Z = $125,000, the cost of a mini computer, software, and peripherals, including modems to allow remote terminal communications. The cost of terminals is ignored, since all Districts already have them. The cost to acquire data, KD, is, say, \$200,000. It is assumed that it will cost 10 percent of the cost of the data, or \$20,000, to process it for Concept Design use, making $\xi = 1.10$.

If a \$60,000/year cost is assumed for operating the centralized data management system, including telephone line costs, allowing for an 8 percent yearly linear increase and a discount rate of 10 percent, gives, for a 5-year horizon, a present value of operating costs of

$$\text{Op. Costs}_{PV} = \$60{,}000 \sum_{y=o}^{4} \frac{1 + (0.08)y}{(1.10)^y}$$

$$= \$60{,}000\ [1.00 + \frac{1.08}{(1.10)^1} + \frac{1.16}{(1.10)^2} + \frac{1.24}{(1.10)^3} + \frac{1.32}{(1.10)^4}]$$

$$= \$60{,}000\ [1.00 + 0.982 + 0.959 + 0.932 + 0.902]$$

$$= \$60{,}000\ [4.775]$$

$$= \$286{,}500$$

The factor ψ, then, is $1 + \frac{200{,}000}{285{,}500}$, or 1.698.

Summarizing,

$Z = \$125{,}000$

$\xi = 1.10$

$\psi = 1.698$

$KD = \$200{,}000$.

Therefore,

$$f_1\ (MCA) = \$125{,}000 + (1.10)\ (1.698)\ (\$200{,}000)$$

$$= \$125{,}000 + \$373{,}560$$

$= \underline{\$498{,}560}$, total cost for 5 years operation of the centralized data management system, including acquisition of the component data.

Mode 1, Centralized Data Management, Equivalent Annual Cost (EAC)

From Eq 40:

$$EAC_1\ (MCA) = [Z + \xi \cdot \psi \sum_{\alpha\epsilon MCA} \sum_{s\epsilon S} \sum_{c\epsilon C_s} f_1\ (P_c)][\frac{i(1+i)^n}{(1+i)^n - 1}] \quad \text{[Eq 44]}$$

$$EAC_1\ (MCA) = f_1\ (MCA)\ [\frac{i(1+i)^n}{(1+i)^n - 1}]$$

For n = 5 years, and a discount rate, as above, of 10 percent:

$$EAC_1\ (MCA) = \$498{,}560\ [\frac{0.10(1.10)^5}{(1.10)^5 - 1}]$$

$$= \$498{,}560\ (0.264)$$

= $\underline{\$131{,}620}$, cost per year to establish and operate the centralized data management system.

Mode 2, District-Level, Ad Hoc Data Acquisition, Present Value

From Eq 38, for Mode 2, the present value for providing data for the entire MCA program for n years is

$$f_2\ (MCA) = \xi \sum_{y=1}^{n} \sum_{\alpha \varepsilon MCA_y} \sum_{s \varepsilon S} \beta_s \sum_{c \varepsilon C_s} \alpha_c\ f_2\ (P_c)\ \frac{e_y}{(1+i)^y} \qquad \text{[Eq 46]}$$

where y = the year 1, 2, ---, n in which the cost occurs

e_y = the inflation rate in year y relative to year 1

i = the discount rate

α_c = the number of times, on the average, analyses are done for alternatives to component c

β_s = the number of times, on the average, analyses are done for alternatives to system s

ξ = a factor to account for the additional data processing for analyses at Concept Design time, $\xi > 1$

$c \varepsilon C_s$ represents the components of $c \varepsilon C_s$ of the systems $s \varepsilon S$ which appear in the facilities α of the MCA program in year y for which LCC analyses will be done

$\alpha \varepsilon MCA_y$ represents the facilities α in the MCA program in year y for which LCC analysis will be done

$s \varepsilon S$ represents the systems $s \varepsilon S$ in the facilities α for which LCC analyses will be done

$$f_2\ (P_c) = m_1 \cdot f_2\ (IA_m) + m_2 \cdot f_2\ (IB_m) + m_3 \cdot f_2\ (IIB_m) +$$
$$m_4 \cdot f_2\ (IIIB_m) +$$

$$r_1 \cdot f_2\,(IA_r) + r_2 \cdot f_2\,(IB_r) + r_3 \cdot f_2\,(IIB_r) +$$
$$r_4 \cdot f_2\,(IIIB_r),$$

where the coefficients m_j and r_j represent the number of times the analyst-designer acquires the data for the calculation of cost for the single component c, and the functions $f_2\,(IA_m)$, $f_2\,(IB_m)$, ---, represent costs to acquire the data represented by the arguments, as described in Chapter 3 (i.e., the cost data for maintenance and repair procedures for components $c \varepsilon C_s$ each time the data is required).

For the present example, assume that LCC analyses will be performed only on the HVAC systems for the BOQ, Administrative, Training, and Maintenance Shop facilities in a single year y MCA program. The MCA program for this hypothetical year y includes the following numbers of the facilities of interest:

BOQ	80
Administrative	20
Training	35
Maintenance Shop	15

The HVAC systems are of several different types, and each consists of seven components; each component requires three maintenance procedures and four repair procedures. The designer will typically consider three systems for each facility; he will consider two components for each one selected for a competing system.

For this scenario, there are therefore the following sets:

$$MCA_y = \{\alpha_1, \alpha_2, \alpha_3, \alpha_4\}$$
$$= \{80 \text{ BOQ}, 20 \text{ Administrative}, 35 \text{ Training}, 15 \text{ Maintenance Shop}\}$$

$$S_{\alpha 1} = \{s\}$$
$$= \{1 \text{ HVAC}\}$$

$$S_{\alpha 2} = \{s\}$$
$$= \{1 \text{ HVAC}\}$$

$$S_{\alpha 3} = \{s\}$$
$$= \{1 \text{ HVAC}\}$$

$$S_{\alpha 4} = \{s\}$$
$$= \{1 \text{ HVAC}\}.$$

That is, there is only one system s, namely HVAC, of interest out of all the systems S that constitute a single facility α, and there is one such HVAC system per facility.

For each selected HVAC system, there are seven components:

$$C_s = \{c_1, c_2, c_3, c_4, c_5, c_6, c_7\}$$

Since an average of three competing systems are analyzed, $\beta_s = 3$. It is assumed, arbitrarily, that 30 percent additional work will have to be done on the component-level data to prepare it for use at Concept Design time, making $\xi = 1.30$.

It is assumed that all designers want to minimize their efforts at assembling LCC data and are content with present values of lump sum life cycle maintenance and repair costs for each component they consider. This data corresponds to $IIIB_m$ and $IIIB_r$ in Figure 1. Eq 35, then, becomes

$$f_2\ (P_c) = m_4 \cdot f_2\ (IIIB_m) + r_4 \cdot f_2\ (IIIB_r) \qquad \text{[Eq 47]}$$

Since the designers have chosen to use lump sum estimates, the knowledge that each component requires three maintenance and four repair procedures is not used, and it is therefore not necessary to know the schedules for the procedures. The designer typically examines two components for each one he chooses, so $\xi = 2$, in Eq 47. Assume that the cost f_2 for acquiring $IIIB_m$ and also for acquiring $IIIB_r$ is \$20. The designer will seek two estimates for each value, so $m_4 = 2$ and $r_4 = 2$ in Eq 47:

$$f_2\ (P_c) = 2 \cdot \$20.00 + 2 \cdot \$20.00$$

$$= \$80.00.$$

The cost summary then becomes, from Eq 46, where, since there is interest only in a single year, $\frac{e_y}{(1+i)^y} = 1$,

$$f_2\ (MCA) = (1.30) \sum_{\alpha = \{80,20,35,15\}} \sum_{s=1}^{(3)} \sum_{c=1}^{(2)} (80.00)$$

$$= (1.30)\ (80 + 20 + 35 + 15)\ (3)\ (7)\ (2)\ (\$80.00)$$

$$= \underline{\$655,200}$$

The total cost for <u>acquiring data</u> alone for this hypothetical situation, for a single year, is then \$655,200.

If the scenario is now changed somewhat to a 5-year period, with the same facility mix, and inflation is allowed to increase at 8 percent linearly, discounting at 10 percent:

$$f_2\ (MCA) = \$655,200 \sum_{y=o}^{4} \frac{e_y}{(1+i)^y}$$

$$= \$655,200\ [1 + \frac{1.08}{(1.10)^1} + \frac{1.16}{(1.10)^2} + \frac{1.24}{(1.10)^3} + \frac{1.32}{(1.10)^4}]$$

$$= \$655,200\ [4.775]$$

$$= \underline{\$3,128,580}$$

where $3,128,580 is the total cost of operating the LCC analysis program described in this section over 5 years.

Mode 2, District-Level, Ad Hoc Data Acquisition, Equivalent Annual Cost (EAC)

From Eq 41:

$$EAC_2\ (MCA) = f_2\ (MCA)\ [\frac{i(1+i)^n}{(1+i)^n-1}] \qquad [Eq\ 48]$$

For n=5 years, and a discount rate i of 10 percent:

$$EAC_2\ (MCA) = \$3,128,580\ [\frac{0.10\ (1.10)^5}{(1.10)^5-1}]$$

$$= \$3,128,580\ [0.264]$$

= $825,945, cost per year to operate the District-level, Ad Hoc Data Acquisition System to support LCC analysis as described in this scenario, with 8 percent per year linear inflation.

Acquisition of Data

The composition of MCA programs in future years is a matter of public record. Component and system identification is most easily done by the designers and their supervisors.

A convenient way to extract relatively reliable data from the experience of the analyst-designers is to convene a panel of experts for 3 days, and to apply the well-recognized Delphi technique to a set of questions posed to the group. Questions are based on known MCA and system composition and are aimed at providing consensus values for costs and replication numbers for Eqs 31 and 35, and values for β and γ, Eqs 30 and 36.

Specific questions that might be posed to the panel of experts or to sources within the Corps of Engineers and the computer industry are as follows:

1. What facilities (by type) are in the MCA program in each year for the next n years? ($\alpha \varepsilon MCA$)

2. How many are there of each type, in each year? ($\alpha \varepsilon MCA$)

3. For each facility type, list the major systems, by generic name (e.g., HVAC, flooring, cladding, roof, fenestration, plumbing, lighting, electrical) which will be subject to life cycle cost analysis. ($s \epsilon S$)

4. For each generic system, for each facility type, list the identifiable kinds of systems that will be considered (e.g., hot water heat, forced air, electrical resistance, solar). ($s \epsilon S$)

5. For each kind of system, for each generic system, list the component <u>categories</u> (<u>not</u> the <u>number</u> of each component in a specific system). For example, a lighting system using fluorescent tubes might be assembled out of luminaires, fluorescent tubes, hangers, wiring, switches, distribution boxes, and circuit breakers. Knowledge of the exact number of each of these components which might go into a specific lighting system is not needed. ($c \epsilon C_s$)

6. For every component, determine which of the data categories (i.e., IA_m, IB_m, ---) of Eq 31 can feasibly be determined. ($f_1(P_c)$)

7. For every component data category just identified, itemize the most probable means of acquiring that data, and the time, resources, and total cost of acquiring it <u>once</u>.

8. For every component data category identified, estimate the number of times data will be sought to ensure consistency and reliability of values. For example, is it probable that an analyst would call, say, three suppliers and average the values given by them? (m_i and r_i, Eq 31)

9. What is the one-time cost for hardware and software to support a centrally managed database? (Z)

10. What is the annual cost of managing, formatting, updating, and distributing the data to users? What is the present value of these annual costs, indexed for inflation, over the next n years? What is this present value of cost of operations as a percent of total data acquisition costs? (ψ)

11. What is the additional cost, as a percentage of total data acquisition costs, of processing component-level data for use at Concept Design time? (ξ)

12. What is the probable number of alternatives a designer would consider (analytically) before choosing a component of any given system? (γ_c)

13. How many alternative systems would a designer typically consider before choosing a particular system to incorporate into a design? (β_s)

14. What will be the pattern of inflation over the next n years?

15. What is the appropriate discount rate i over the next n years?

16. What is the time horizon in years, n?

Values for variables ξ and ψ are best determined by an analyst, considering the amount of effort and number of calculations involved. A reliable value for Z can be determined only after the magnitude of data volume has been established, after considering the MCA program composition, and after the meeting of the panel of experts suggested above. Discussion with hardware vendors and software contractors can establish this cost within acceptable accuracy.

Values for inflation e_k and the discount rate i are fixed at OCE or at a higher level.

Exercise of the Models

The models are well-defined, and, with data available, present no major problem to a programmer-analyst to prepare computer programs to do the calculations.

Costs

1.	Panel of Experts		
	5 @ 3 days = 15 man-days @ $500/day	= $7500	
	Travel and Subsistence		
	5 x 3 x $50 = $ 750		
	Air Fare 5 x $650 = 3250	4000	
	Total		$11500
2.	Preparation for Panel Meeting		
	5 man-days @ $200/day		1000
3.	Conducting Panel Meeting		
	3 man-days @ $200/day		600
4.	Summarizing Results of Panel Meeting		
	2 man-days @ $200/day		400
5.	Determination of values for ξ and ψ by analyst		
	2 man-days @ $200/day		400
6.	Determination of value for Z by analyst		
	2 man-days @ $200/day		400
7.	Exercise of Models		
	Programming: 5 man-days @ $150/day	$ 750	
	Computer time	500	
	Preparation of data	200	
	Total		1450

8. Preparation of Report

2 days @ $200/day	400	
Drafting and reproduction	200	
Total		600
		$16350
Contingency @ 10%		1650
TOTAL		$18000

6 SUMMARY

This study has developed methodology, examined calculations for life cycle cost analysis in support of the design functions of the MCA program and has analyzed the impact of Concept Design and Advance Final-Final Design on obtaining the data needed to perform the calculations.

Criteria were developed for selecting modes of supplying the required data to the users; using these criteria, two promising modes were selected: (1) a centralized database (Mode 1) and (2) ad hoc data acquisition by the analyst-designer (Mode 2).

A general economic model for data supply was developed for each mode. A plan for applying the two economic models to a hypothetical design situation was drawn up, and costs to implement the plan were estimated. The models were shown to be well-defined, and it was determined that the programmer-analyst could easily prepare programs to do the calculations if the required data is available.

APPENDIX

TRIP REPORTS

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INFORMATION SYSTEMS AND TECHNOLOGY

13 July 1981

TRIP REPORT "Excerpt"

1. Travellers: Dr. E. L. Murphree, Sage Systems Corporation
   Mr. Robert D. Neathammer, Construction Engineering Research Laboratory

2. Date: 9 July 1981

3. Destination: Ft. Worth District, U. S. Army Corps of Engineers, Ft. Worth, TX

4. Purpose: Discuss procedures used at the District for performing Life Cycle Cost Analyses in connection with design for the Military Construction Program, Army (MCA); determine how District would use a central data base for LCC studies, if provided, and what features of a central data base would be required for maximum efficiency; determine alternative data sources and procedures the District would use, if a central data base were not provided.

5. Narrative:

a. The Mechanical, Architectural, and Estimating Sections, Engineering Division, were visited and the above-cited areas of interest were discussed with Section Chiefs and other professionals in each Section. Each interview is covered in a separate section, in the following.

b. Mechanical Section: Mr. Paul Armbrust, Chief.

The section uses percentages for LCC studies, not exact costs, and LCC is used only when there are conflicts with design criteria.

The HVAC simulator program TRACE, developed bv the Trane Corp., is used by the Section in the HVAC design process.

For LCC studies now, maintenance and repair (M&R) costs are estimated as percents of initial cost of the HVAC system under study. The rationale is that the less equipment (lower initial cost) there is, the lower will be the M&R costs. For differential cost analyses, M&R costs are not believed to be large enough to make a difference in the analyses of alternative systems. The ASHRAE Handbook of Fundamentals (1) has been considered a likely source of M&R data, should the District be required to do a detailed LCC analysis on a design. However, that reference has been consulted recently, and the expected data ($/yr/sq ft for generic types of systems) was not found.

The following points were made, when the question was raised about how the District would proceed if it had to develop an M&R data base of its own for LCC studies.

(1) The District would prepare scenarios of the expected M&R processes, i.e., the steps M&R personnel have to go through to get specific tasks done, ordered in time. Another way to look at this is to do a mental "walk-through" of each M&R cycle. The results would be sets of sub-tasks that collectively constitute the M&R tasks expected to be performed for each system considered.

(2) Manufacturers' operating manuals normally give schedules for maintenance, including descriptions of the tasks which have to be done, and when. What is missing is data on required skills, consumable materials and parts, and times to perform the tasks.

(3) There is little on repairs in operating manuals beyond "trouble-shooting" hints about likely breakdowns. There is nothing about either the probable timing of specific breakdowns, or required skills, consumable materials and parts, and time to make the repairs when breakdowns do occur.

(4) In order for Mechanical designers to use data in operating manuals, it must be available to them. At present, designers do not have access to operating manuals; the manuals go directly to users at the installations. If data from operating manuals is used in LCC studies in the future, then every District will have to be supplied with manuals on every piece of equipment they might use in designs. Data from manufacturers could possibly be biased; the reliability is unknown. If one or more of the trade publishers (e.g., Chilton (2)) publishes a Rate Book for mechanical work, this might be a good source of times to do certain tasks. A range of task times, with allowances built in to allow, say, for relative difficulty in getting to the equipment requiring maintenance or repair, would be of more value to the designer than a single value.

(5) Even when task times are known, there is great difficulty in predicting wage rates of maintenance workers, unless they are Government employees, in which case grades fix the range of wage rates.

(6) Geographical differences in costs are probably not great. Factors can probably be used to handle this with acceptable accuracy.

For initial cost estimates, Mechanical designers now use such standard cost references as Means (3). There is little feedback to the designers from the Estimating Section, and consequently little information transfer.

While it may be feasible to assemble reliable data on M&R costs for individual pieces of equipment in an HVAC system, it is another matter to do the same for systems assembled from various parts. The complexity of the system itself, apart from that of the individual components, is a major factor in the M&R for the system as a whole. For example, the connections between components are themselves subject to breakdown. Further, there is an effect on each component from the system itself: the breakdown experience of any component is influenced by the performance of the other components in the system. A valve which fails and allows a coolant to drain can cause major failures throughout the system of which it is a part. It may be that allowing a percent of initial cost is the best approach to M&R of the system, over and above that of the individual components.

The question was raised about whether the reliability of LCC analysis is good enough to include M&R costs. Is the value of M&R data worth what it costs, whatever that cost may be?

If OCE does not provide a data base to support LCC studies, then the District will get data from manufacturers and trade journals such as Heating, Piping and Air Conditioning Magazine (4) and The Specifying Engineer Magazine (5). M&R studies would probably not be accumulated; a new one would have to be done for each case, as it arises.

Energy studies are done now on 10-12 projects/year now. TRACE (or occasionally BLAST) is used, and it takes 5-6 runs for each project before final design. Cost is $750 to $1500 for each facility for these energy studies. No LCC analysis is done unless 2-3 alternatives are very close on energy costs, or there is a conflict with design criteria. On these studies, it is assumed that all "ownership" costs are the same on all competing systems.

The Section has no preference on the medium for presentation of the M&R data, should OCE provide a central data base. A technical manual would suffice. Curves, with cost ranges, are more easily used than are tables. A recommended approach is to present the costs as percents of initial costs of the equipment.

c. Architectural Section: Mr. J. Uriel Quinones, RA, Chief; and Mr. Roy Perkins.

Several years ago, the Architectural Section was doing LCC analyses on architectural features of design jobs, but the practice was stopped by the Southwest Division. Simple design jobs were requiring 1-2 man-weeks for LCC studies on architectural features such as painting and flooring replacement. Some designers (2-3) accumulated a data base to use locally. The M&R data accumulated and used in the analyses came from the designers' experience and from experience of the Facilities Engineers at installations in the District. It was known that biases were in the data, but they were the best data available, and no other sources were available.

A computer program written by Mr. Don Baldwin, OCE, was used for the calculations, and the input forms for the program dictated the data that was sought. Once the basic decisions about M&R timing had been made, and the data gathered, the analyses were more or less routine.

No reasons were given about why the Division stopped the analyses, but it was possibly due to the fact that the LCC analyses were causing some deadline slippages.

The architectural designers do not feel that they have the expertise to do LCC analyses, even if they were provided with a data book and a computer program to do the calculations. Computer analysis is preferred over hand calculation methods. If LCC is required, the Architectural Section would seek to have the Estimating Section do it all.

At present, only informal, "common-sense" economic decision-making is done in connection with the designs. At the end of each phase

(Concept, Advanced Final, Final) of design, the design goes to the Estimating Section for an estimate of initial cost. It is rare to change a design.

The architectural designers now use Sweet's Catalog (6) for design data; there is, however, no M&R data there. If required to do LCC studies, the designers would go to the Facility Engineers for data based on their experience. A second potential source of M&R data is maintenance contractors, who must have a data base on the types of items they regularly service or maintain in order to remain competitive. The District has had good cooperation from maintenance contractors in the past.

If the Section is required to do LCC analyses, then more manpower in the Section will be required to do it. At present, about 15% of the designs are done in-house, 85% by A-E firms. A separate group within the Section does reviews of A-E designs.

The user often defines many basic design features, leaving little room for the designers to impact the M&R costs. At 1391-time, many major architectural design decisions have already been made. By Pre-Design Conference time, the major design decisions are made. LCC analyses must be performed in support of these major decisions if it is to have any important effect on long-term costs.

d. Estimating Section: Mr. Wiley Jones, Chief.

The Section only does estimates for initial costs. Data usually comes from the Berger Building & Design Cost File (annual) (7); a locally-developed format, ENG Form 150 (1959), is the standard for all estimates.

On request, the Section provides, from standard cost references, data on costs for specific M&R tasks, e.g., painting. These data include costs for consumables and labor; the designers must decide, however, <u>how often</u> the task is repeated. No information on M&R is known by the Estimating Section to be available from any manufacturer.

If LCC analyses were requested often, repeats of the same alternates, the Section would eventually build up a file of "standard" analyses, and simply refer to them as necessary.

The Section has no suggestions on how a designer might locate or generate M&R schedules for building components.

The mission of the Section is seen as the duty to determine whether a project is at or near budget. There is no procedural mechanism to promote feedback of cost consequences of design decisions to the designers.

6. Conclusions:

a. While in the recent past, the Ft. Worth District has performed LCC analyses, little or no such analyses are currently being done. The

Chiefs, Mechanical Section and Architectural Section, are well acquainted with both the procedures of LCC analysis and the data requirements.

b. The Chief, Mechanical Section, had specific logical suggestions as to how he would proceed if he were required to perform LCC analyses and to generate data locally to support such analyses. His suggestions should be examined closely in connection with the economic study of LCC data base alternatives.

c. Major architectural design decisions, wherein LCC analysis can often make the greatest impact, are often made before the architectural designers see the project. Accordingly, if LCC analysis does not play a part in decision-making at project planning time (1391 and Pre-Design Conference times), little will be gained in economies through use of the technique during design.

d. The estimating Section is not organized to support the designers in decision-making. To require such support from the Section will imply major reorganization and redirection of the Section.

7. References:

(1) ASHRAE Handbook of Fundamentals, The American Society of Heating, Refrigerating and Air Conditioning Engineers, 345 East 47th Street, New York, NY 10017.

(2) Flat Rate Book, Chilton Company, Chilton Way, Radnor, PA 19089, published periodically.

(3) Building Construction Cost Data, Robert Snow Means Company, Inc., 100 Construction Plaza, Duxbury, Mass. 02332, published annually.

(4) Heating/Piping/Air Conditioning, Reinhold Publishing Co., 2 Illinois Center Bldg., Suite 1300, Chicago, IL 60601, published monthly.

(5) Specifying Engineer, Cahners Publishing Co., Inc., 5 South Wabash Ave., Chicago, IL 60603, published monthly.

(6) The Sweet's System, Sweet's Division, McGraw-Hill Information Systems Co., 1221 Avenue of the Americas, New York, NY 10020, published annually.

(7) Berger Building Design Cost File, Van Nostrand Reinhold Co., 135 W. 50th St., New York, NY 10020, published annually in regional editions.

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INFORMATION SYSTEMS AND TECHNOLOGY

11 August 1981

TRIP REPORT "Excerpt"

1. Travellers: Dr. E. L. Murphree, Sage Systems Corporation
Mr. Robert D. Neathammer, Construction Engineering Research Laboratory

2. Date: 5 August 1981

3. Destination: Sacramento District, U. S. Army Corps of Engineers, Sacramento, CA

4. Purpose: Discuss procedures used at the District for performing Life Cycle Cost Analyses in connection with design for the Military Construction Program, Army (MCA); determine how District would use a central data base for LCC studies, if provided, and what features of a central data base would be required for maximum efficiency; determine alternative data sources and procedures the District would use, if a central data base were not provided.

5. Narrative:

a. The Military Design Branch, and the Mechanical-Electrical Design and Estimating Sections, Civil Design Branch, Engineering Division, were visited and the above-cited areas of interest were discussed with Section Chiefs and other professionals in each Section. Each interview is covered in a separate section, in the following.

b. Military Design Branch: Mr. Louis J. Santin, Chief; Mr. D. W. Reynolds, Chief, Design Section B; Mr. W. D. Jackson, Reg. Architect, Design Section A.

The Military Design Branch has within it two Design Sections, A & B, each of which has architectural, civil, and structural designers. The designers perform the designs and also do quantity take-offs for estimating construction costs. After the take-offs have been done, the Estimating Section of the Civil Design Branch does the pricing for the estimates. The Mechanical-Electrical designers operate the same way, doing the take-offs and passing them on to the Estimating Section for pricing.

Some LCC analyses have been done in the past, and data has been a problem. The ASHRAE Handbook (1) has been useful, but no data has been forthcoming from the installations on M&R experience.

During the mid-1970's, LCC analyses were done on projects. While the FE's at installations were not oriented toward providing the types of data required for the analyses, they did provide material from which data were developed for the analyses.

The Facilities Engineers' "Red Book" (2) is not a useful source of data, since all costs for a single type of facility are lumped together, with no discrimination. The potential user has no indication what facility categories the listed costs are based on (new, old, renovated, etc.).

The District has used the engineered M&R programs (Engineered Performance Standards, or EPS) approach, in which they have assumed a program for each type of maintenance and repair job expected to be done. Data to support this approach includes materials and supplies in a pseudo-man-hour cost. [NOTE: This precludes the possibility of using tabulated man-hour data for manpower planning and materials and supplies tabulations for procurement planning.]

It has been found to be costly and time-consuming to collect raw data and then process and manipulate it as necessary to reflect the actual situation in any given study. Engineers must apply judgement to the data in any data base, and in order to do so must have confidence in their reliability. A full program of LCC analysis in support of the District's design program will require at least one full-time person to keep procedures and data current.

During the 1974-1977 period, when LCC studies were being done, a computer program supplied by OCE, written by Mr. Don Baldwin, was used for the calculations. TRACE was used on energy studies. The designers were not supported by the estimators, who did not have the data required, so the designers were forced to gather data themselves.

In order to be most useful, LCC must be done in support of design decisions at concept phase. It is important for the designers to have leeway at concept design phase, to take advantage of local conditions (e.g., site characteristics, materials available in the area, capabilities of local contractors). Should LCC be required, it will be very helpful to the designers to have a quick, easy way to guide an LCC study, to give a quick look with limited information, then go into more detail with better data, if warranted. An interactive data base, with data at different levels of detail, at the systems level for concept design, more detail for final design, would be most useful. An integrated interactive LCC analysis system could provide data at the best level of detail and also perform the calculations. A feature of such a system that could lead new users through the process would be valuable. A centralized computer-based interactive system for both data and procedures, is needed for LCC analysis to be economical and practical. A drawback is that relatively few people in Districts have computer skills. On the other hand, data published in book form are always obsolete. No problem is foreseen in having A-E's use CE programs and data to do LCC studies.

Production of the studies is heavily labor-intensive, and must be well-organized to improve efficiency if the studies are to be routinely done. One LCC analysis by hand is enough; once an analyst understands the process and is convinced a computer program is doing what he wants done, the entire process can be automatic. The reports should reference standard procedures and programs, and not show calculations. They should show assumptions, key data values, and results, only. The reports should be streamlined physically, for ease in production, storage, and use, by standardizing as much as possible. Once a study has been done on a much-used component (e.g., floor tile), that study should be referenced, and not re-done over and over.

Even when LCC analysis shows a lower LCC cost on a high initial cost item, regulations and policies on first cost may control the final decision. Effective use of LCC analysis may require changes in current regulations and policies.

c. Mechanical-Electrical Design Section, Civil Design Branch: Mr. Thomas E. Nissen, Chief.

The mechanical designers, both in-house and out-of-house, use TRACE and BLAST for energy studies.

M&R data may be available from commercial maintenance firms. Local utilities can provide rate data. Engineering judgement is seen as the best source for expected lives of components and expected replacement costs. Engineered M&R procedures (i.e., EPS, as referred to earlier in this Report) must be developed for use with current labor and parts costs. This kind of "ideal maintenance schedule" is the only feasible way to insure valid comparisons between alternative designs.

While historical data may exist for some kinds of equipment, solar systems do not have a long history. How does a designer estimate future M&R costs for solar systems? Engineered M&R procedures seem to be the only answer.

Experience in the Section with LCC analysis has been that the designers quickly learn which systems are best for each locality and for typical building sizes. Analyses often show that competing systems don't differ as much as the accuracy of the analysis techniques. Continuing to repeat studies when results are known in advance does not make economic sense.

The Estimating Section does not see a design until the concept design is complete. Most often, the estimators do both quantity take-off and cost extensions. Designers sometimes do take-offs, but the estimators always put dollar values on the estimate. Under the present arrangement, designers have only a general idea of costs.

Should the District be required to do LCC analyses on a regular basis, changes will have to be made in the operating procedures. The designer should do the analyses, not rely on another party to do it on request. Engineers need to have confidence that a computer program is doing, in fact, what they think it is doing. Both data and programs should be available on a computer, for ease in both use and updating. Geographical data is vital. A centralized data base, accessible to all users, is highly desired. The use of a book and attempting to keep data current is not the way to do it.

If data is not provided through a centralized data base, then designers will have to seek their own data. Telephone calls take the time of two or more people, in addition to the costs of the call itself. Duplication of effort will be the result of this approach.

The benefits of centralized data base and procedures are several:

(1) Consistency of analyses within each District and nationally.

(2) Quality of data can be controlled, and this quality can be reflected in the analyses.

(3) Costs of building and maintaining separate data bases at every District can be avoided.

In order to make doing the analyses palatable to the designers, basing both data and procedures on an accessible computer is the best way to do it. Designers do not want to "run a program." They want an <u>answer</u> to <u>use</u> in their design work. A "user-friendly" LCC analysis system patterned after PLATO BLAST, with "hand holding" for the inexperienced user, is probably the best approach.

Doing LCC analyses without accurate, reliable data is demoralizing to the engineer, who rapidly loses respect for the system, and certainly for the analyses themselves; and by extension, for all such analyses. A single, well-maintained data base will lower the wide variation now found in similar analyses.

d. Estimating Section, Civil Design Branch, Engineering Division: Mr. Frank Ching.

For cost estimating, the Estimating Section prefers a centralized system, with standardized data and procedures, making for ease of review. The Section now uses many sources for data for initial cost estimates, and is now considering a locally devised computer data base for all estimating. It will take one man full time, perhaps, to maintain it.

Policies often prevent higher initial cost designs from being chosen, even if M&O costs are lower than those of competing designs or if the entire life cycle cost is lower. Regular reliance on LCC techniques for design decisions may require some changes in policies.

The Section favors LCC analysis in support of designers, but stresses the need for uniformity in data and procedures.

6. Conclusions:

a. The District has been involved in preparing many LCC studies in past years, but only prepares such studies on request at present. The knowledge of procedures is relatively wide-spread in the District.

b. There is a relatively well-developed belief that LCC matters, both data and procedures, should be centrally controlled and maintained, and that a computer system, easily available to the designers, is the best way to proceed.

c. The same concerns about unknown quality of data were voiced here as elsewhere. Historical data from any source is not expected. The engineered M&R procedures approach was promoted as the most reasonable way to provide uniform reliable M&R data for the analyses.

d. The Estimating Section does not seem to fit into the operating procedure that will probably emerge when LCC analysis is done on a regular basis.

7. References:

(1) ASHRAE Handbook of Fundamentals, The American Society of Heating, Refrigerating and Air Conditioning Engineers, 345 East 47th Street, New York, NY 10017.

(2) The Facilities Engineers' Red Book.

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INFORMATION SYSTEMS AND TECHNOLOGY

17 July 1981

TRIP REPORT

1. Travellers: Dr. E. L. Murphree, Sage Systems Corporation
Mr. Robert D. Neathammer, Construction Engineering Research Laboratory

2. Date: 15 July 1981

3. Destination: Savannah District, U. S. Army Corps of Engineers, Savannah, GA

4. Purpose: Discuss procedures used at the District for performing Life Cycle Cost Analyses in connection with design for the Military Construction Program, Army (MCA); determine how District would use a central data base for LCC studies, if provided, and what features of a central data base would be required for maximum efficiency; determine alternative data sources and procedures the District would use, if a central data base were not provided.

5. Narrative:

a. The Mechanical, Architectural, and Estimating Sections, Engineering Division, were visited and the above-cited areas of interest were discussed with Section Chiefs and other professionals in each Section. Each interview is covered in a separate section, in the following.

b. Architectural Section: Mr. Leonard Borton, Chief; Mr. Logan B. Dixon, Jr.

About 10 years ago, the Savannah District was doing LCC studies, but ceased doing so. The work then was a joint effort with "Cost Engineering," or estimating, and the designers. If the District was required to do LCC studies now, M&R data would have to come from users and the manufacturers. Data from manufacturers, which would probably reflect "average" use, would be in error to a certain extent for application to military facilities. Military bases are not "average" users, and the wear and tear on building components is not "average."

The Savannah District has been responsible for $250 million in design and construction since 1962. The target is to do 25% of this design in-house, the remaining 75% being done by A-E firms. Some design review is now being done on contract with A-E firms. A requirement for LCC analysis will place more work on the designer; A-E's will do the LCC analyses as part of the design contract, and will want higher fees to cover the extra work. In the long run, however, the additional cost will not likely be much.

Economic analyses during design will change the way designers work, and will change the relationships between designers and cost estimators. The successful application of LCC to the design process requires rapid assessment of costs for design decisions. A basic question in this matter is whether the designers and estimators could (or should) be taught to do the analyses together, as a team; or the designers should be taught to do the analyses themselves, using references for procedures and data.

Special requests for LCC studies are done now, as the knowledge of how to perform them exists in the District.

The general feeling is that an OCE-produced data base would be the best solution to providing uniform, reliable data for the analyses. Hand calculations are very time consuming and are of questionable benefit as a learning experience. Computer programs for the calculations are recommended. A data base on a computer, which can be kept up to date easily, is seen as a better alternative than printed data books, which are apt to be out of date and expensive to maintain.

c. Mechanical Section: Mr. William Plunkett (Energy Analysis).

The Section uses BLAST for in-house design. TRACE is usually the choice of A-E firms, however. M&R costs are assumed to be the same for any competing system, and are ignored for LCC analyses. If LCC analysis were required, cost data would be needed for high cost M&R items only. Accuracy of data is suspect.

Typically, analyses are done on 3-4 fan systems, 4-5 alternates on solar systems, and perhaps as many as 6 different configurations on a central HVAC plant design.

Good quality LCC analyses require reliable data, but M&R data on large equipment is not known to be available anywhere. Repair data may be available from users, if it can be tied to maintenance programs actually in place. Maintenance contractors might be a source of reliable data; universities also might have good records on M&R.

It would be helpful to users, if BLAST had default tables built in, to avoid the level of data now required for BLAST input.

d. Mechanical Section, Design: Mr. William Sanford, Assistant Chief, for Mr. W. H. Leavengood, Chief (who arrived later).

Some 11-12 years ago, the District tried doing LCC analysis. At that time, attempts were made to get M&R data from Facility Engineers, with no success at all. No useful records on M&R were kept at the installations. The District then went to the manufacturers for data, notably TRANE, with some success. TRANE remains the best source of M&R data.

The District does not get involved directly with M&R of the facilities. Data must come from users (and, perhaps, manufacturers).

The tending to more complex HVAC systems to save energy is resulting in more breakdown-prone control systems, forcing a greater M&R load on the Facilities Engineers to provide repairs on sophisticated equipment. Skills for making these repairs often do not exist at the FE, and more outside contracts are required to provide the required skills. The savings in energy are, then, being offset somewhat by higher M&R costs of the more complex systems. One cannot assume that M&R costs are the same for all HVAC systems and omit them from LCC analyses.

Experience with LCC analyses has shown that, for a given facility type, comparative studies of alternative designs produce much the same results. After a few for a facility type, there is no point in continuing to do them.

The design load at the District is around 150 projects at any time. With only 7 mechanical designers, including 2 trainees, most work goes to A-E firms. More would probably go out-of-house if LCC analyses were required. A-E designers do LCC analyses themselves, during the design process. Some analyses are known to have been done at concept design phase. Sources of their data are not known; large A-E firms possibly have their own data bases.

For mechanical work, TRANE is a leader because of the TRACE program, which was made available in 1975-76. They have a staff of experts to answer questions on call. While designers use TRANE data, they cannot know in advance what manufacturer's equipment will actually be bid and installed by the contractor. There is considerable difference in equipment which meets specifications. Therefore, data for analyses must be representative, and useful at design time. Specific models cannot be specified, so even if data on specific models is in the data base, it cannot be used with confidence.

e. Estimating Section: Mr. Ammons, Chief; Mr. Jack Kaylor, Estimator.

With a load of around 150 projects a year, and a much larger work load expected by 1984, the Section now spends 4-5 man days for each final estimate, and less time on each concept estimate. The Section averages about 4 estimates on each project, as it moves through the design and contract award process.

Data for estimates comes from standard cost references such as Means (1). Means also publishes a data book on renovation costs and labor times for standard tasks, which the estimators often use to estimate renovation and major repair costs. The Section does not do LCC analyses and has no suggestions as to sources of M&R data. On request, they provide data on materials and labor times to designers doing LCC analyses. As to how often equipment or building components must be replaced, the user's (FE's) might have data. The Section does not do LCC analyses, does not have the data, and has only elementary knowledge of the techniques involved.

The Section often gets current cost data from suppliers and contractors, to supplement costs from standard cost references.

6. Conclusions:

a. The District has had some experience in the past with LCC analysis, but does not do it now in support of the design process.

b. Mechanical designers routinely do energy analyses with BLAST, and are aware of the M&R consequences of complex HVAC systems, but are not explicitly considering differential M&R costs when comparing alternative system designs.

c. There is an awareness that routine use of LCC in the design process will fundamentally alter the way designers work, and possibly the relationship between designers and estimators.

d. LCC analysis is foreign to the current estimating process and to the mission of the Estimating Section, as understood by the estimators.

e. BLAST would be more useful if it did not require such detailed input data.

f. No opinions were expressed as to a centralized data base.

7. References:

(1) Building Construction Cost Data, Robert Snow Means Company, Inc., 100 Construction Plaza, Duxbury, Mass. 02332, published annually.

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INFORMATION SYSTEMS AND TECHNOLOGY

TRIP REPORT

1. Travellers: Dr. E. L. Murphree, Sage Systems Corporation
   Mr. Robert D. Neathammer, Construction Engineering Research Laboratory

2. Date: 9 September 1981

3. Destination: Office, Chief of Engineers, U. S. Army Corps of Engineers, Pulaski Building, Washington, D. C.

4. Purpose: To meet with Dr. Larry Schindler, Technical Monitor for Life Cycle Cost research at CERL, and to discuss results of the interviews at the Ft. Worth, Savannah, and Sacramento Districts. To discuss contents of final report, Contract No. DACA88-81-C-0014, dated 1 June 1981.

5. Narrative:

A presentation was made to Dr. Schindler on the results of the information gathering trips made to the Ft. Worth, Savannah, and Sacramento Districts.

Dr. Schindler stated that the information obtained as a result of the trips supported his own belief that a centralized computer-based data base to support LCC analyses would be more economical than the alternative of requiring each designer to locate the data he needs for an analysis.

The point was made by Dr. Murphree that, while it appears that this is true, we have no hard data to support this position.

Dr. Schindler put forth the question of the benefits to be gained by doing life cycle analysis at all, and requested that the report address the problem of establishing the economic benefits, if any, of doing LCC analysis, versus not doing it.

E. L. Murphree

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Marphree, E. Lile
Economic analysis models for evaluating costs of a life cycle cost data base. - Champaign, Ill : Construction Engineering Research Laboratory, 1984.

57 p. (Technical report ; P-164

1. Buildings - life cycles. 2. Buildings - economic aspects. 3. Architectural design - economic aspect. I. Title. II. Series : Technical report (Construction Engineering Research Laboratory) ; P-164

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